

J-2X Test Articles using FDM Process

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And Phil Steele (ICRC)*

www.nasa.gov

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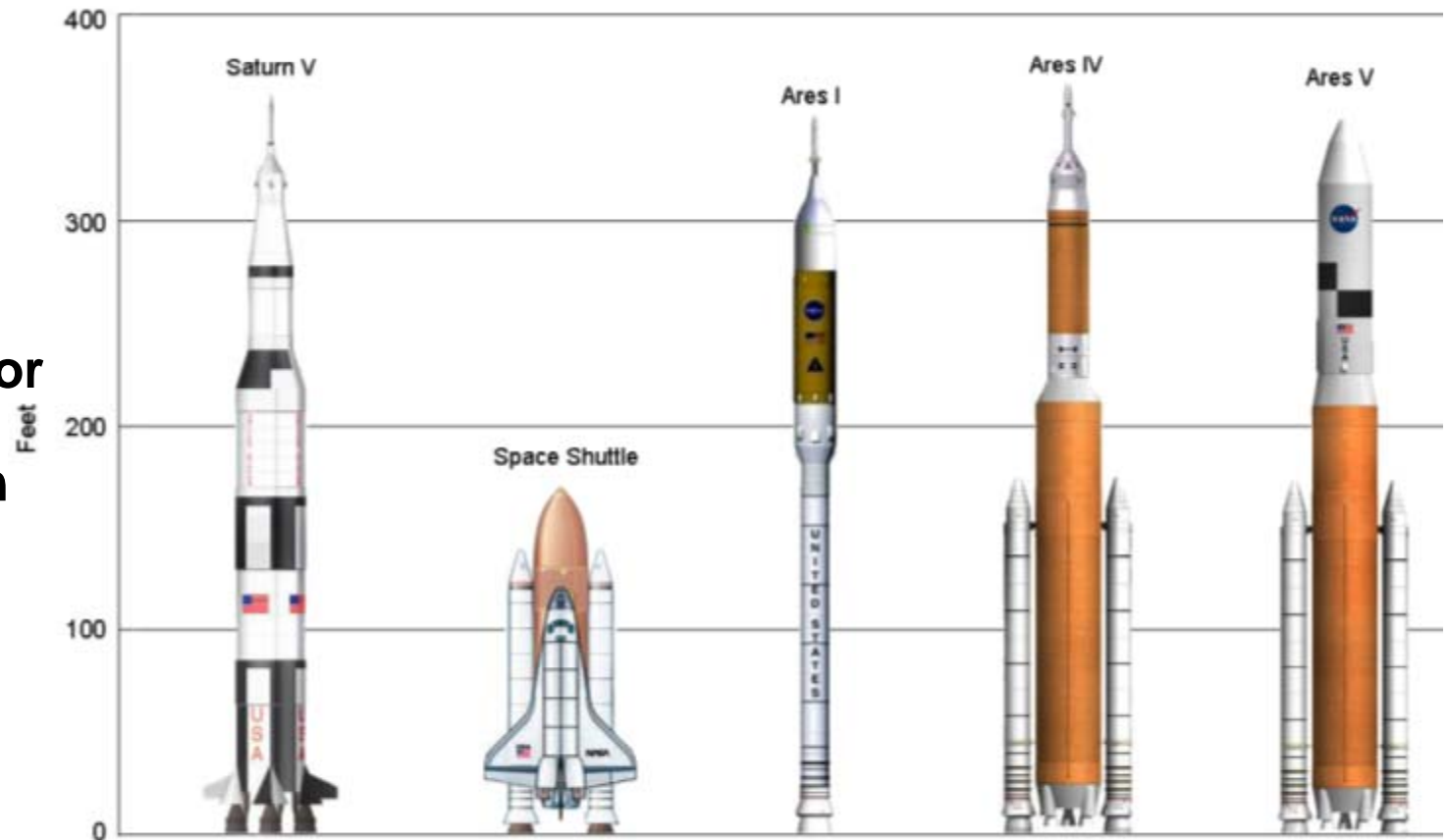
Contents

- ◆ **Introduction to the J-2X**
 - History
 - Today
- ◆ **Built Parts in the FDM Process**
 - Material Test Article
 - Film Coolant Test Article
- ◆ **Benefits of FDM**
- ◆ **Areas of Improvement**
- ◆ **Questions**



Introduction

- ◆ Saturn V was used for the Apollo program from 1967 until 1973
- ◆ Space Shuttle is currently in use and is an orbiter
- ◆ Ares I is the crew launch vehicle being developed for Project Constellation
- ◆ Ares IV no longer in development
- ◆ Ares V is the cargo launch component for Project Constellation

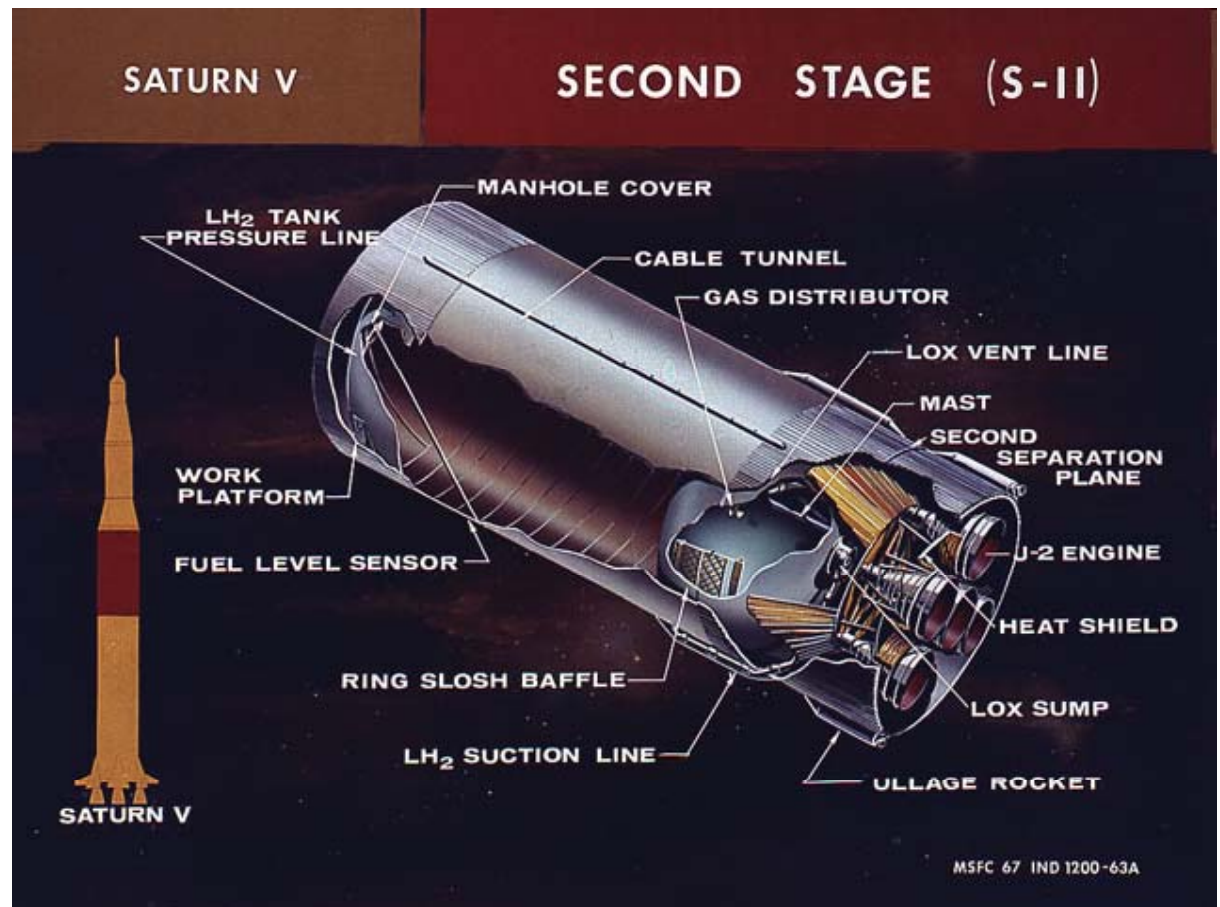




Introduction

◆ A Brief History

- Rocketdyne created the J-2 for the Saturn V rocket
 - It was the largest production liquid hydrogen fueled rocket engine before the Space Shuttle main engines
- A unique characteristic at the time was the ability to re-start after shutdown
- Five J-2 engines on the upper-stage of the Saturn V
- One on the third stage of the Saturn V





Introduction

◆ Today

- The J-2X is a variant of the J-2 engine
 - It was originally planned to use the J-2X only for the Earth Departure Stage
 - With expense for
 - converting the SSME from ground-started to air-startable engine
 - constructing new SSMEs
 - pre-firing SSMEs for each mission
- NASA decided to adopt the J-2X for the second stage of the Ares I and Ares V
- This allows NASA to launch the Ares I rocket within 3 years after retiring the Shuttle in 2010

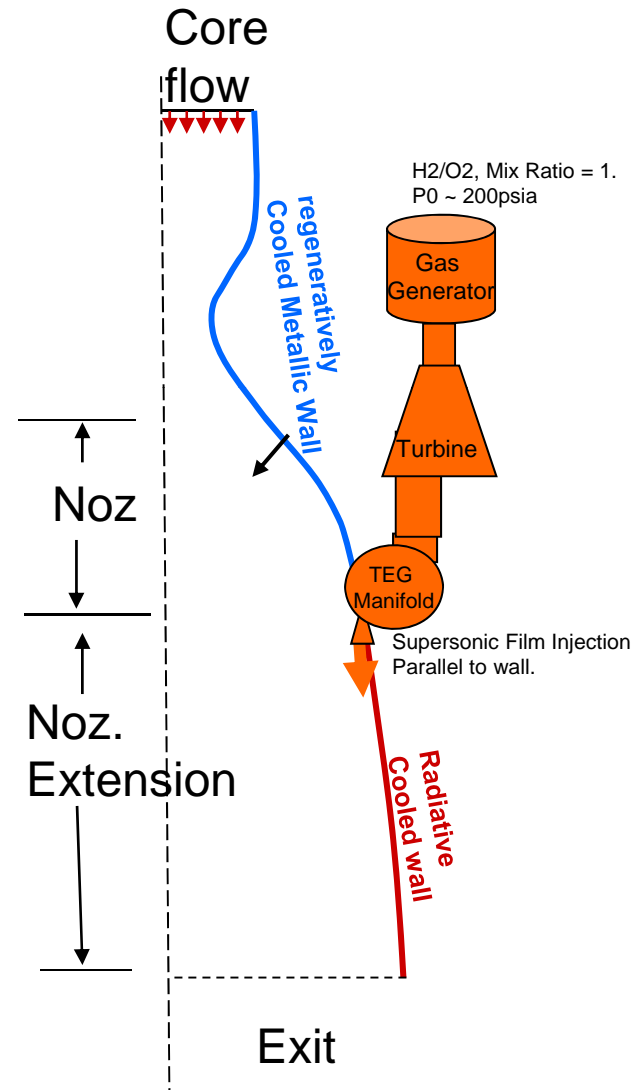
One of the engineering challenges is cooling the Nozzle Extension sufficiently





Introduction

- ◆ The J-2X uses Turbine Exhaust Gas (TEG) to cool the nozzle extension.
- ◆ Motivation of the Cold Flow Testing
 - Reduce the uncertainty in the predicted thermal environment of the nozzle extension.



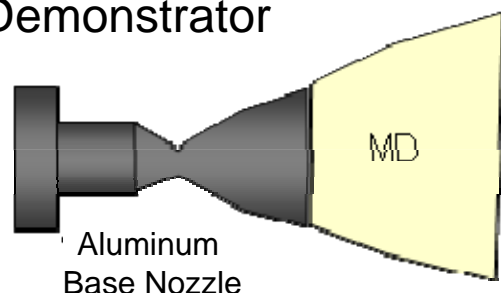


Cold Flow Test Approach

◆ The cold flow testing used existing hardware for the nozzle base.

◆ Two RP Parts were fabricated for the nozzle extension

- Material Demonstrator



Part Objective:

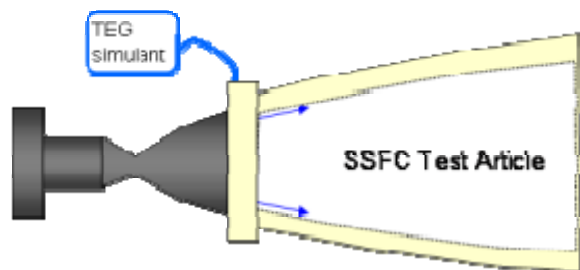
Determine if material will work for nozzle extension.

- how to build and machine
- will it survive testing loads
- can it be instrumented for temperature and pressure measurements.

Determine wall temperature measurement technique.

Develop and prove data acquisition methods..

- Film Coolant Test Article



Part Objective:

Obtain test data: wall temperatures with different film cooling rates and temperatures.

The manifold injects simulated turbine exhaust gas (TEG) to act as a film coolant to the nozzle extension.



1st Part Built, Material Demonstrator

Material Demonstrator

◆ Material: “White” polycarbonate (PC)

- An additional 0.01 of material was added, so the surface could be machined
- Objective: Test the polycarbonate material in a fluctuating thermal environment, test the rigidity of the FDM part, develop instrumentation techniques and develop data acquisition methods.

◆ Steps

- Machined the “wetted” and joint surfaces of the test article using a lathe; a smoother surface finish was required for air flow testing and turning on a lathe ensured the test article was concentric throughout the nozzle curvature.

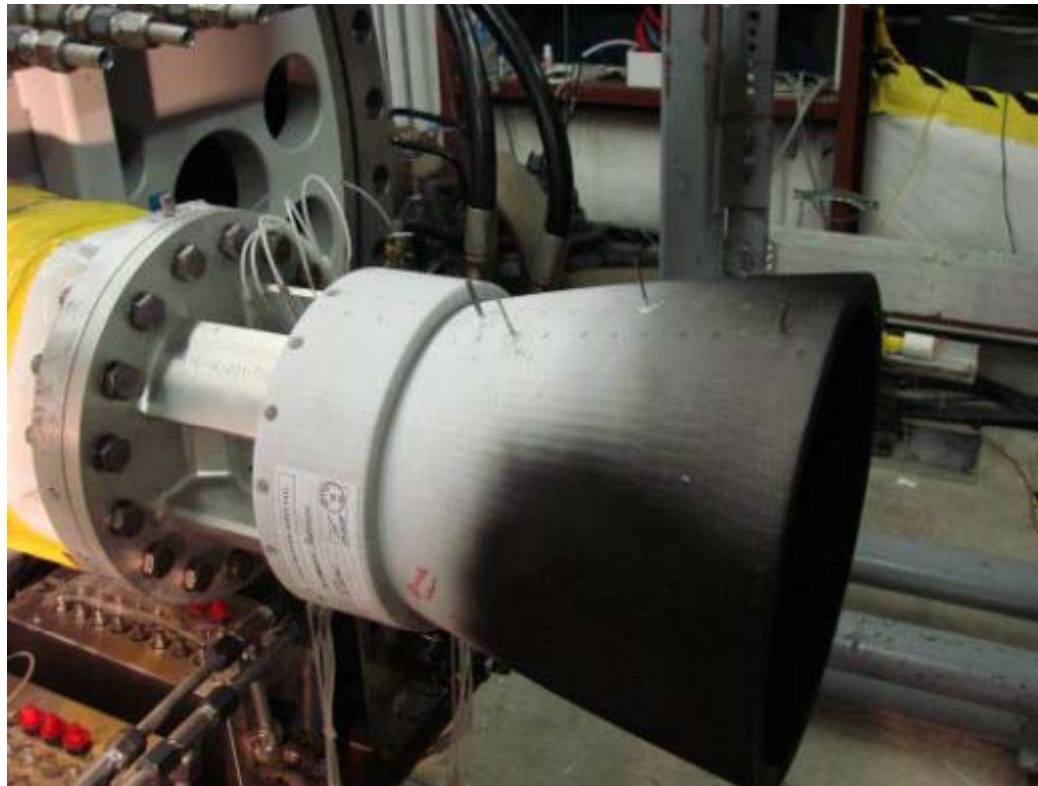




1st Part Built, Material Demonstrator

◆ Material Demonstrator

- Steps (continued)
 - The test article was sprayed with a flat black paint for IR camera emissivity requirements and to seal any porous spots and attached to the test stand. The article was heat cycled twice at 180° F to ensure it stayed concentric and circular. The initial test was a success.

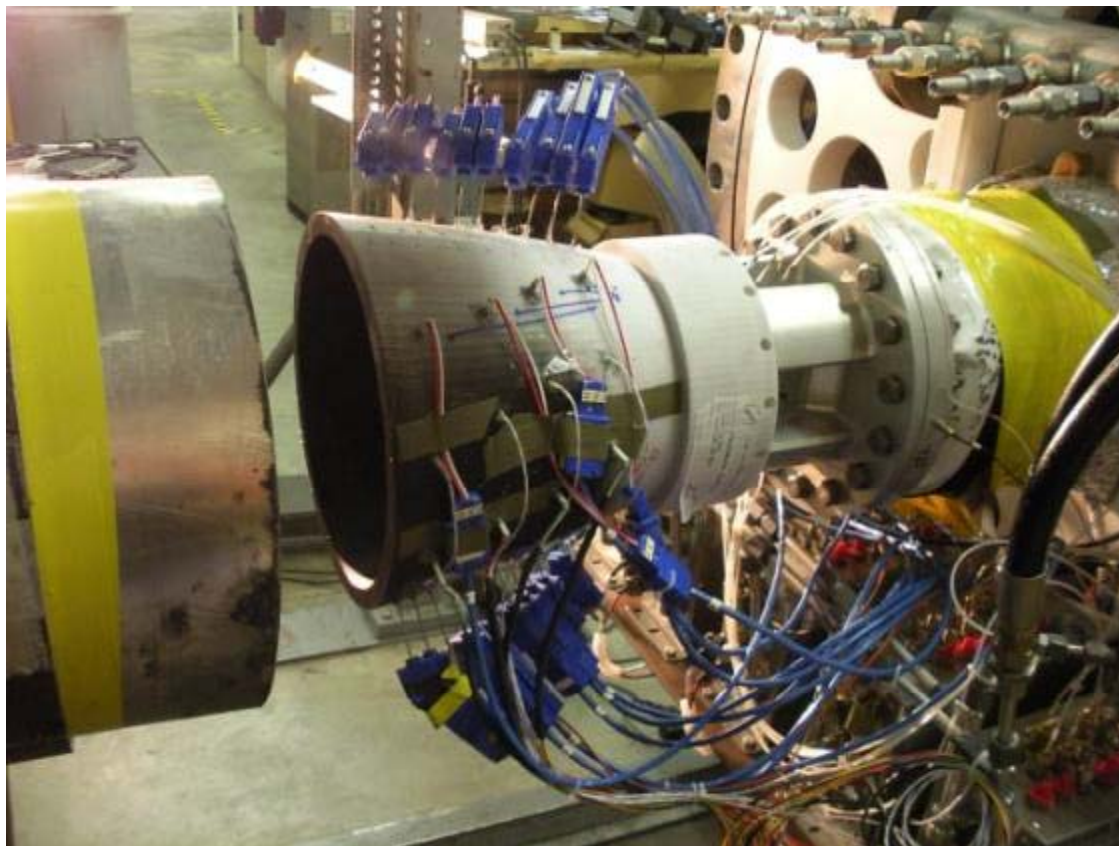




1st Part Built, Material Demonstrator

◆ Material Demonstrator

- Steps (continued)
 - Instrumentation and data acquisition
 - The test article was fitted with multiple thermal testing instruments; “homemade” thermocouples, thermistors, and resistance temperature devices (RTDs).





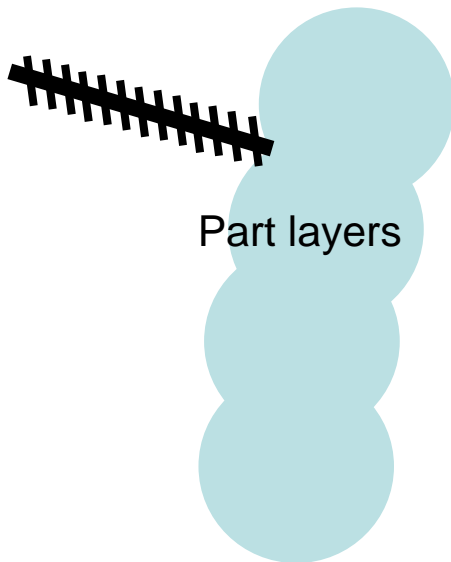
1st Part Built, Material Demonstrator

◆ Material Demonstrator

• Steps (continued)

- There was difficulty drilling directly into the test article with small diameter drill bits. 1/8th inch bits and larger were no problem.
- A variety of temperature measurement instruments were tried..
- The in-house fabricated 'button' thermocouples, shown below on the right, proved to work the best.
 - The desired measurement was adiabatic wall temperature. Wanted minimum influence of the temperature/thermal mass of the plastic.

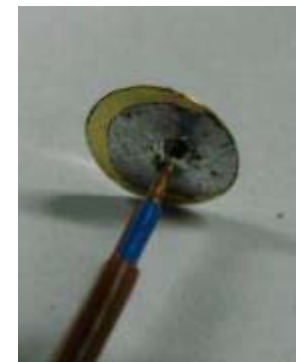
Drill bit



Part layers



0.28" dia

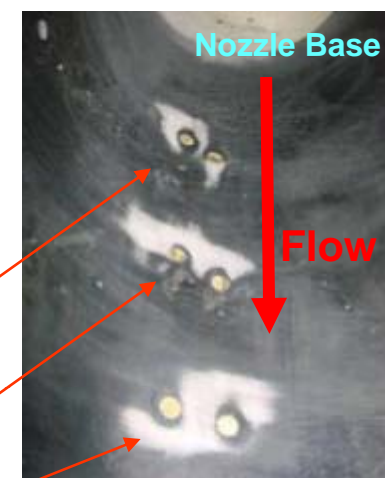
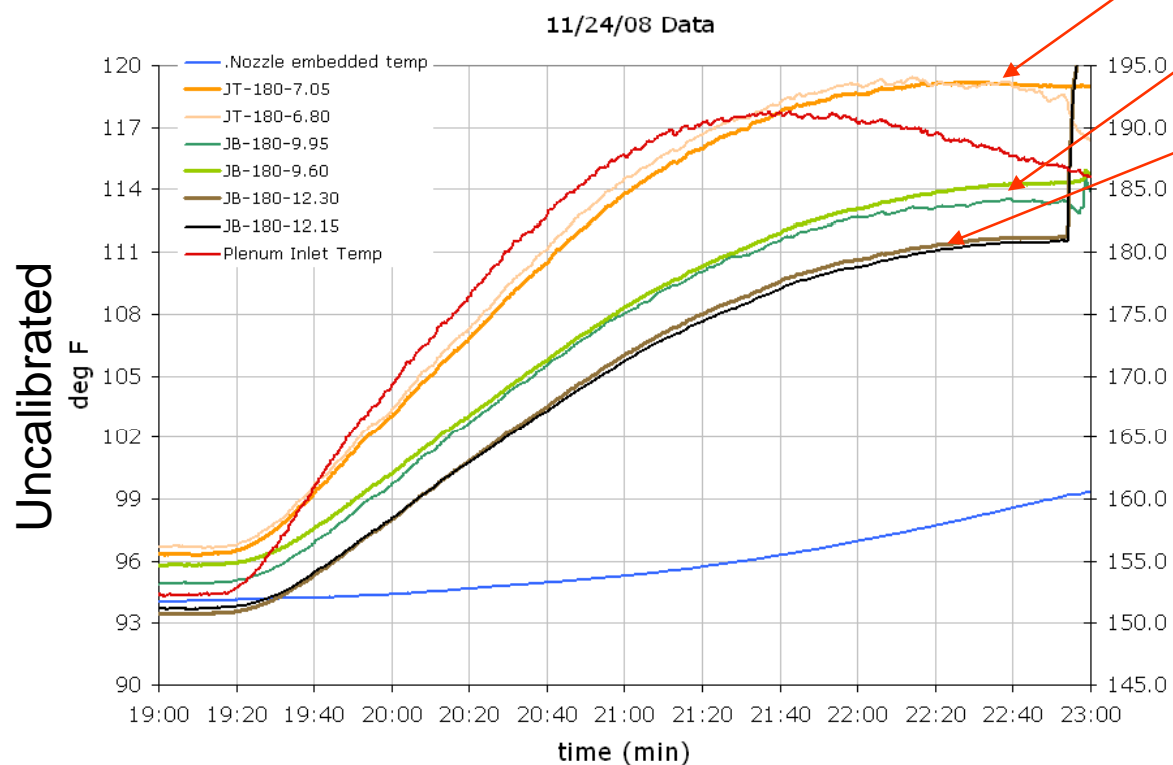




1st Part Built, Material Demonstrator

◆ Material Demonstrator

- When the temperature increased, the thermocouples responded quickly
- The axial temperature distribution was as expected





2nd Part Built, “Test Article”

◆ Film Coolant Test Article

- Material: “white” polycarbonate for nozzle extension; “black” Polycarbonate/Acrylonitrile Butadiene Styrene for the manifold (PC – ABS blend)
 - The manifold has internal channels, so Water Works support was used during fabrication
- Objective: Obtain measurements of the adiabatic wall temperature with different film coolant flow rates. The information will be utilized to create film coolant effectiveness curves. These curves can be scaled to the actual J-2X conditions.

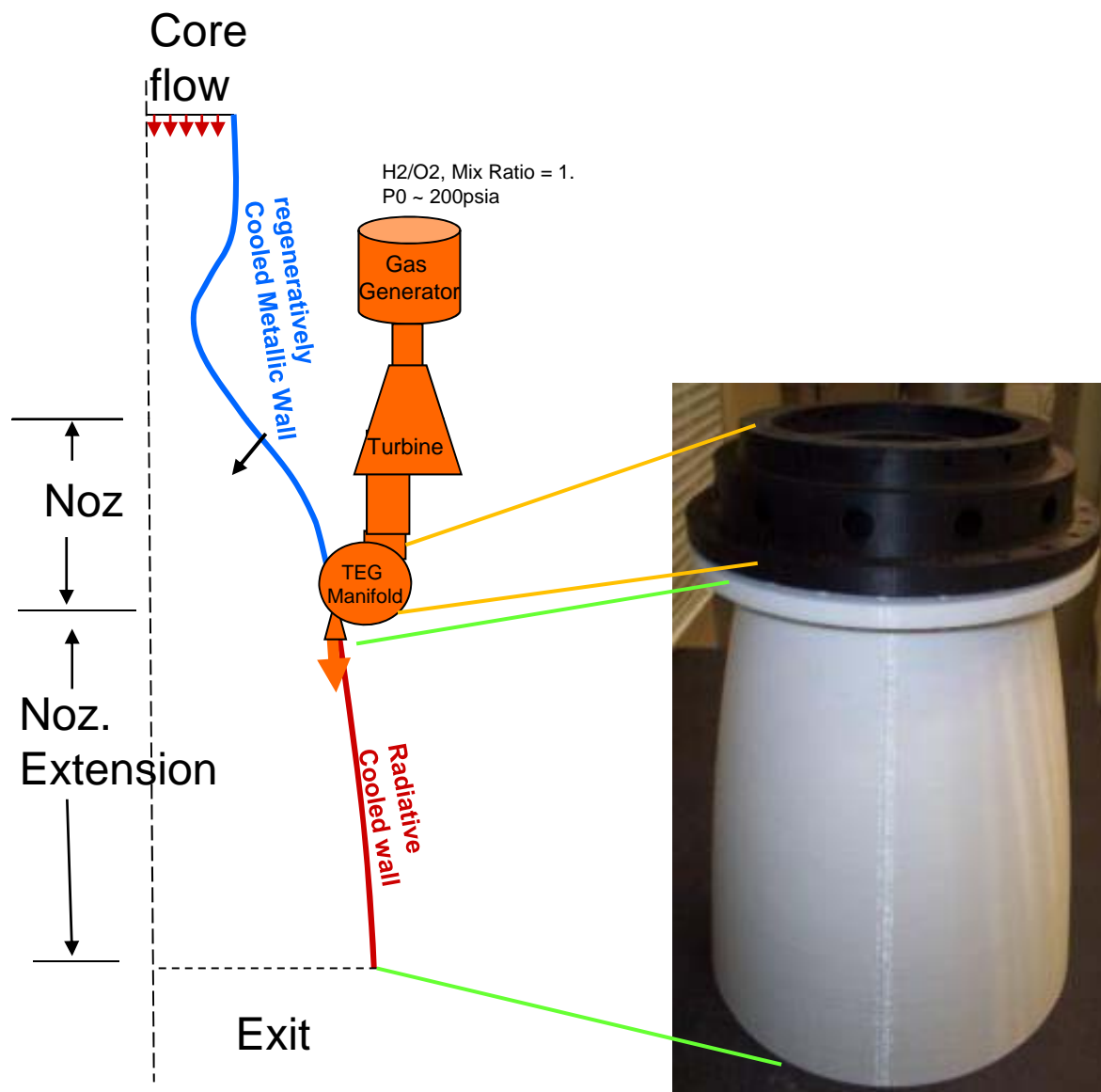


Pre-machined Test Article



2nd Part Built, “Test Article”

◆ Film Coolant Test Article

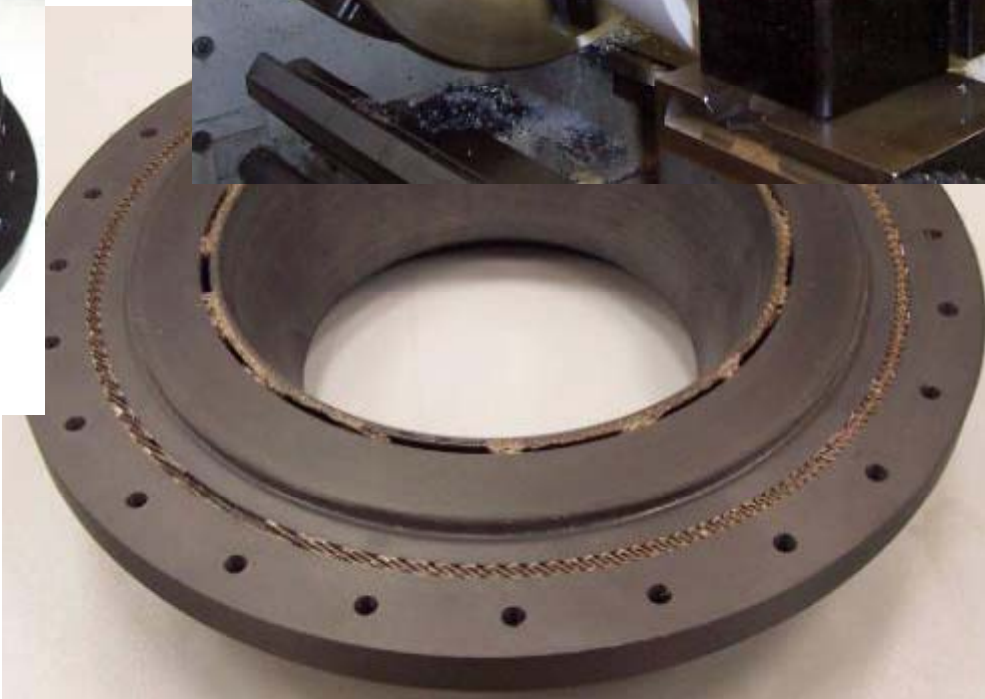




2nd Part Built, “Test Article”

◆ Film Coolant Test Article

- Also needed to be machined.
- Supports were kept in the manifold to help support the part when it was machined.





2nd Part Built, “Test Article”

◆ Film Coolant Test Article

- The supports were dissolved away allowing air flow to travel in the channels of the manifold.

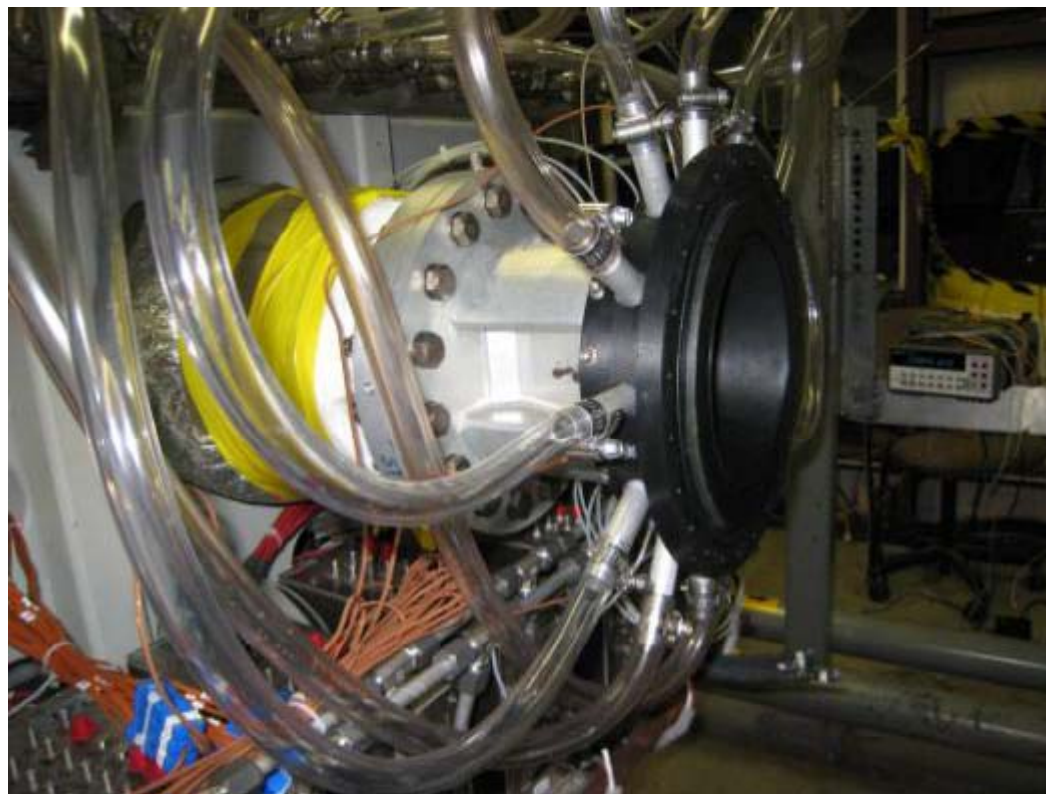




2nd Part Built, “Test Article”

◆ Film Coolant Test Article

- Currently is being attached to the test fixture.
- Temperatures will range between 40 - 150° F with 15 psi absolute in the manifold.
 - The J-2X temperature will be around 5500° F at the nozzle and 600° F from the TEG/manifold.

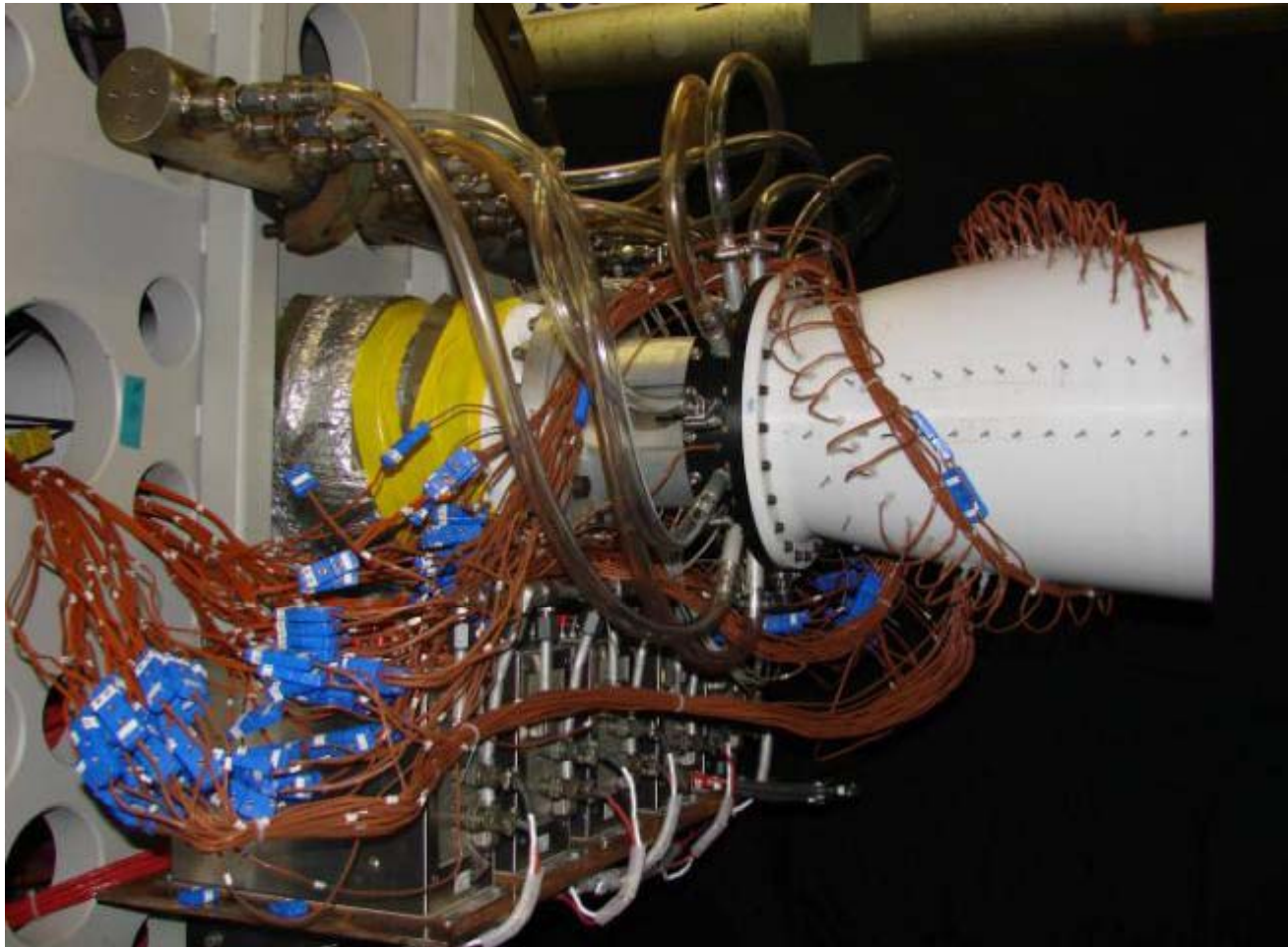




2nd Part Built, “Test Article”

◆ Film Coolant Test Article

- Initial setup



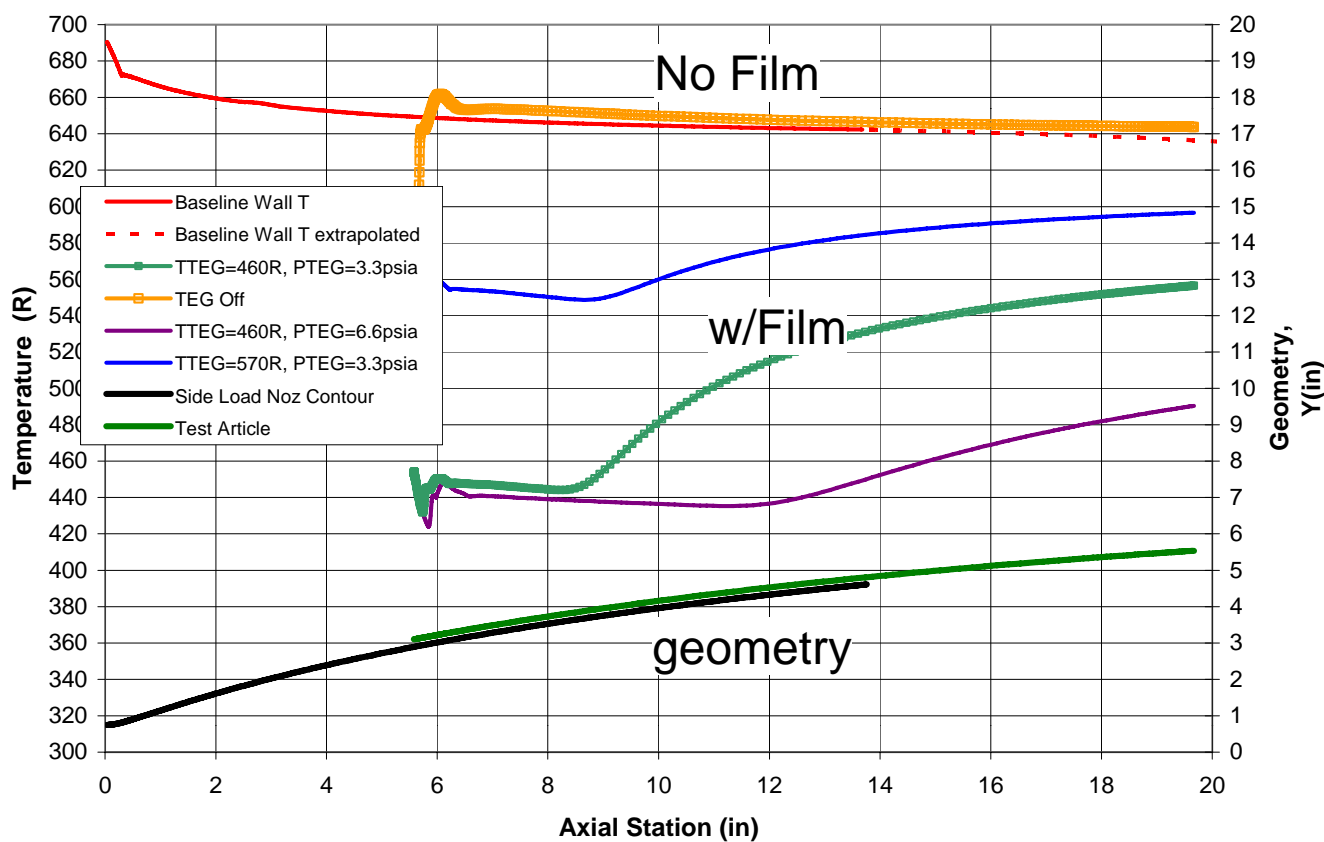


Part Built

◆ Film Coolant Test Article

- Pre-test CFD analysis with a temperature hot flow of 250° F.

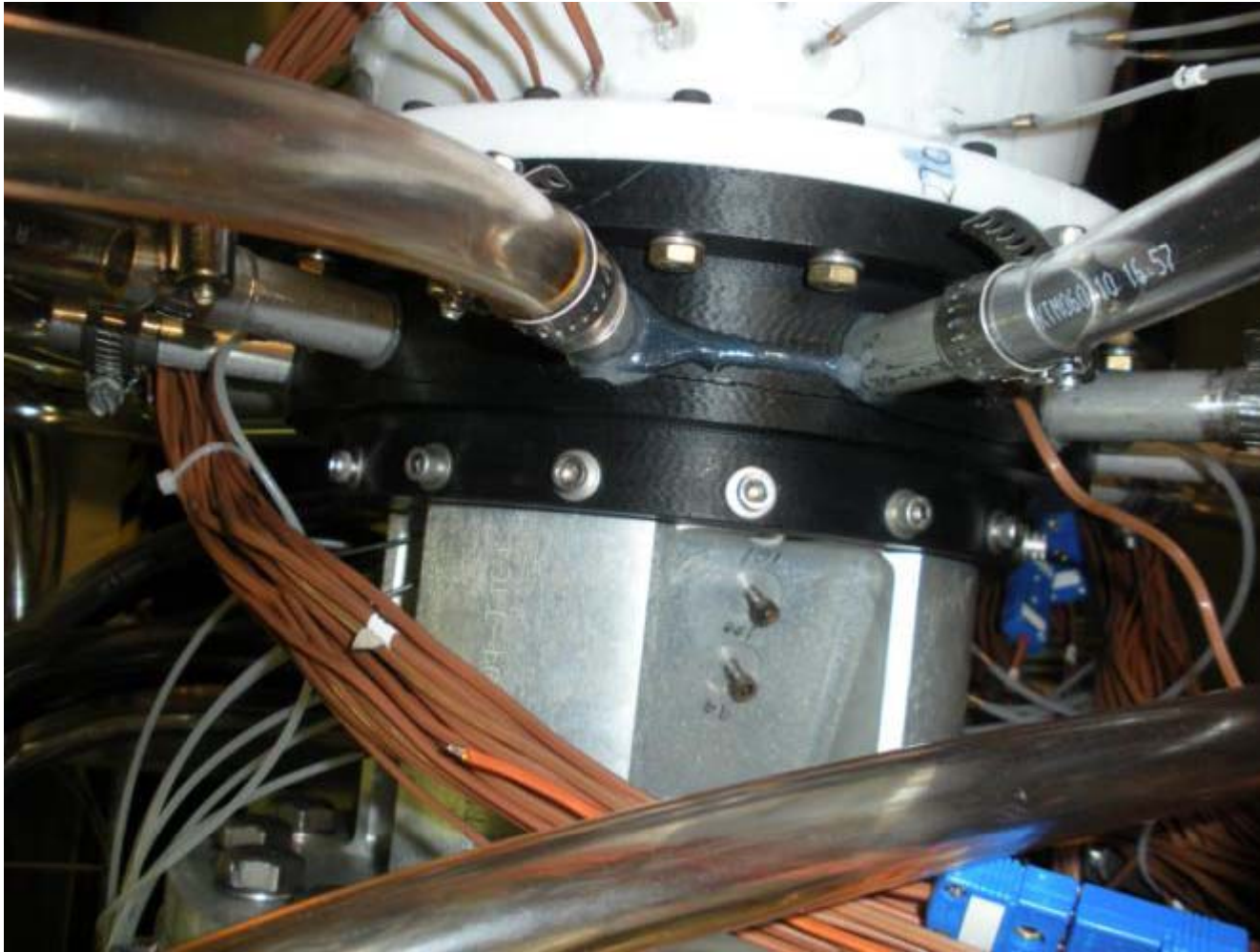
T_{wall} (Adiabatic), $T_{hot_total} = 710R$, $P_{hot_total} = 200psia$





2nd Part Built, “Test Article”

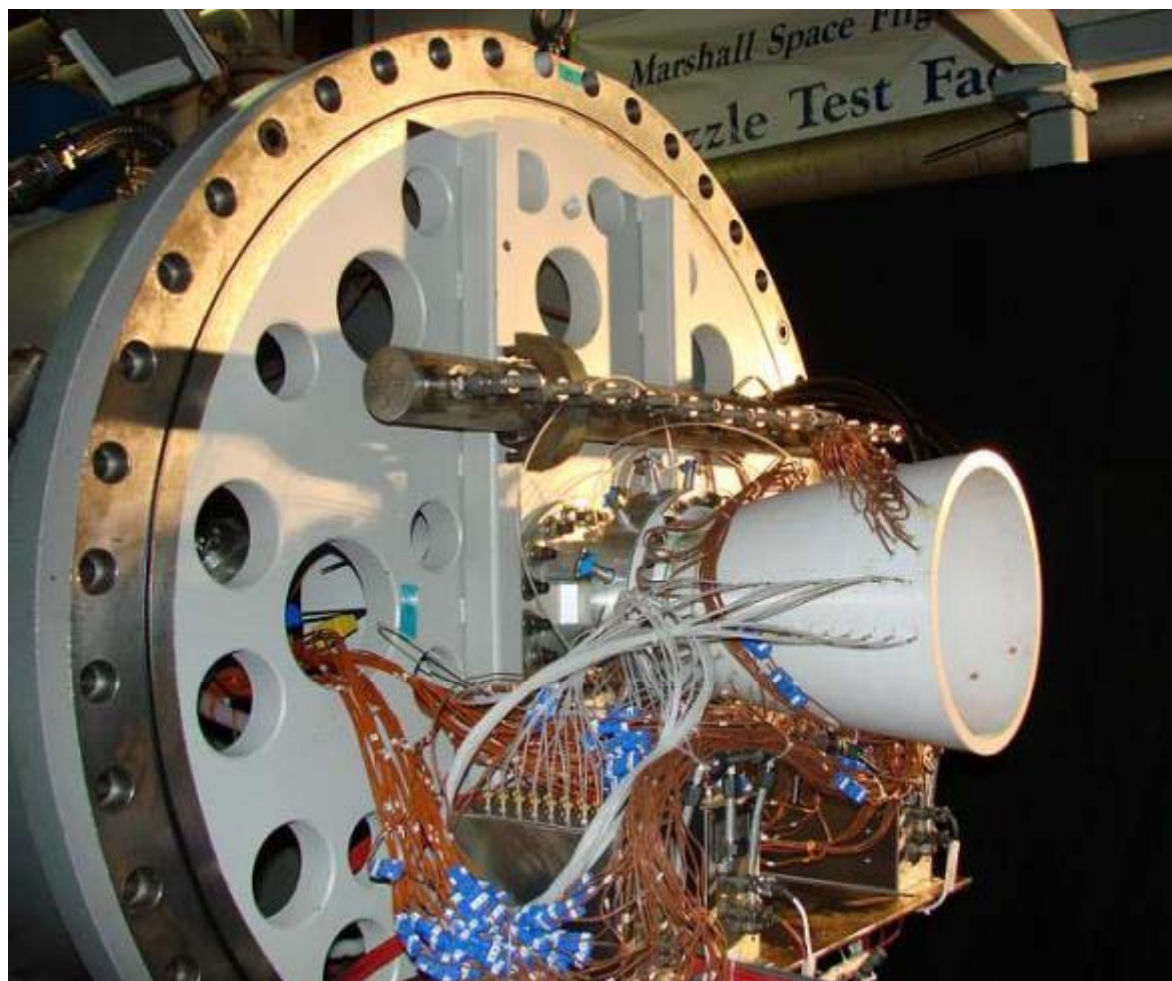
◆ Film Coolant Test Article





2nd Part Built, “Test Article”

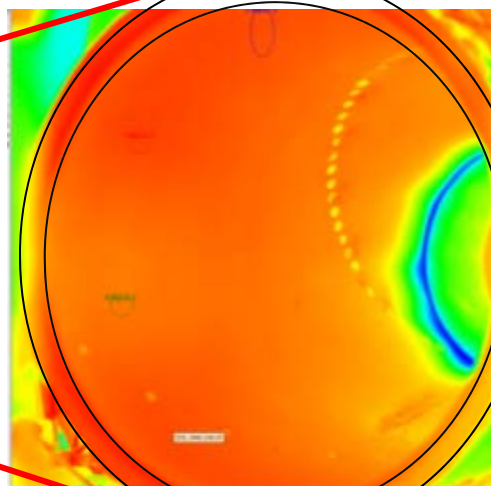
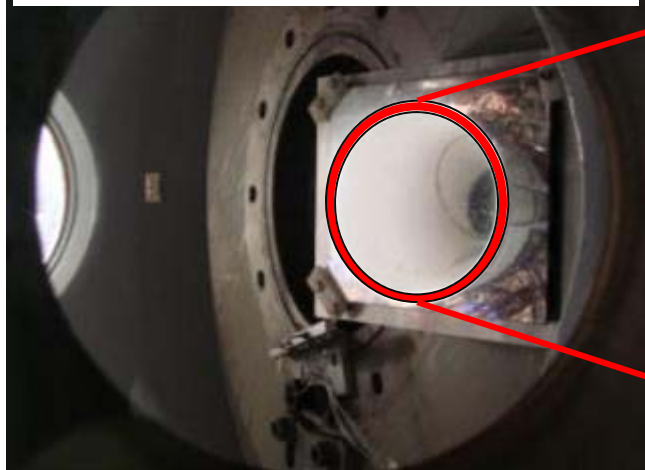
◆ Film Coolant Test Article





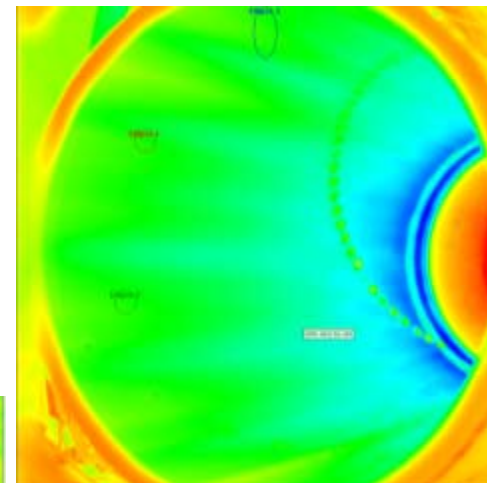
2nd Part Built, "Test Article"

Test article visible.

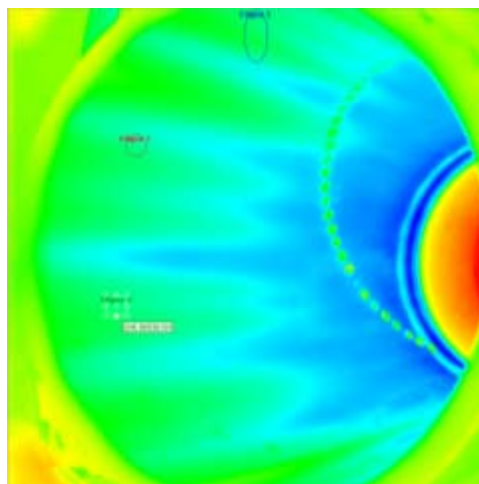


IR image, prior to start

IR image, immediately
after start



IR image, at end of test

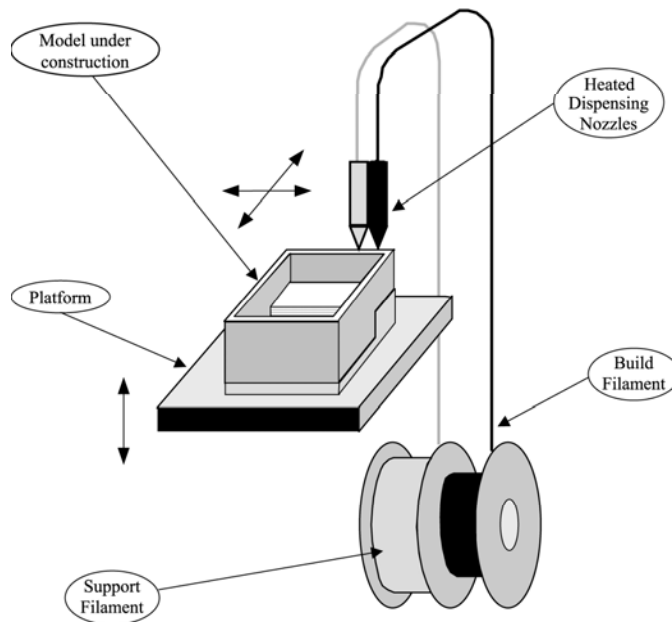


IR image of wall temperature,
uncalibrated (at this time)



FDM Benefits

- ◆ **Why were the parts created in the Fused Deposition Modeling system?**
 - At the time, it had the largest build area at 14" x 16" x 12"
 - The material properties
 - Except for tracking, the test articles could be drilled and tapped relatively easily
- ◆ **Cost savings of \$24k – \$44k.**





Areas of Improvement

◆ The surface finish

- Even if the ID surface is smooth enough for air flow testing, it still needs to be machined to ensure the dimensions of the wall (need better accuracy).

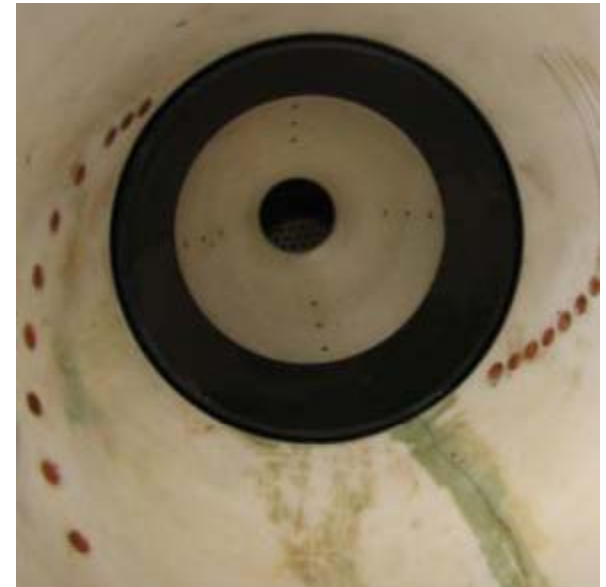
◆ Material properties

- Withstand higher temperatures

◆ Deformed to be slightly out of round

- Based on experience with the Material Test Article, 0.030 was added to the ID of the Film Coolant Test Article to compensate. This still deformed slightly, so next time, 0.1 will be added to the ID.

◆ Low cycle thermo fatigue





Questions

